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Integral Field Spectroscopy with the Gemini 8-m Telescopes

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Abstract. We give an overview of the current and future IFU capabilities on the Gemini 8-m telescopes. The telescopes are well-suited to integral field spectroscopy and both telescopes will have optical and near-infrared IFUs within the next few years. Commissioning for the GMOS IFU on Gemini North has begun recently and it is now available to the community. Future integral field instruments will take advantage of wide-field adaptive optics systems.

1. Introduction

The high image quality and large collecting areas of the Gemini 8-m telescopes make them well-suited to integral field spectroscopy. On smaller telescopes signal-to-noise considerations have forced integral-field units (IFUs) to have either coarse spatial sampling (e.g. INTEGRAL, DensePak, SAURON) or fine sampling of the highest surface brightness targets (e.g. OASIS, TEIFU). More collecting area, a smaller diffraction limit, and new technology in today's 8-10 meter telescopes means that higher signal-to-noise spectra of finer spatial structures can be obtained. Therefore, the first generation of instrumentation on Gemini will include optical and near-infrared IFUs on both telescopes: GMOS and NIFS instruments on Gemini North, and GMOS and GNIRS on Gemini South (see Table 1). This paper summarizes the capabilities of the telescopes and these instruments.

While they are sensitive from optical through mid-infrared wavelengths, the Gemini telescopes are optimized for observing in the near and mid-infrared. Special features of the telescopes include minimizing the mass above the primary mirror in order to lower the thermal background and improve airflow over the mirror, future low-emissivity mirror coatings, daytime climate control, and a tip/tilt chopping secondary. In addition, both telescopes will have facility adaptive optics units that will be able to feed a near-diffraction-limited beam to any instrument. Therefore, Gemini will be able to deliver image quality in the near-

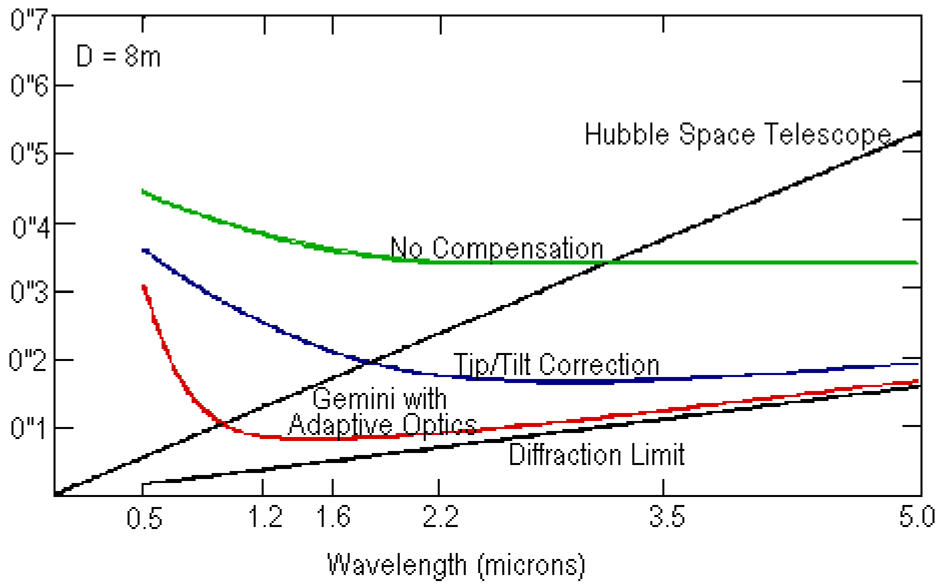

Figure 1. Predicted optimal image quality versus wavelength for HST and an 8-meter telescope with three levels of correction: no correction, tip/tilt correction, and adaptive optics. The Gemini telescopes always use tip/tilt correction and will eventually have facility adaptive optics systems that can feed any instrument. Therefore, in the near-IR the image quality produced by Gemini is equal to or better than that produced by HST.

infrared about a factor of two better than HST (Figure 1). The Gemini IFUs have been designed to work with the expected image quality from either tip/tilt or adaptive-optics corrected beams. The rest of this paper briefly describes the capabilities of each Gemini integral field unit in approximate order of when it will come into service.

Table 1. Summary of Gemini Integral Field Instruments

Instrument/ Location	FOV	Sampling	Wavelength Range	R
GMOS GN and GS	$7'' \times 5''+$ $3''\!.5 \times 5''$	$0.2''$	0.4–1.1 μm	500–8000
GNIRS GS	$3''\!.2 \times 4''\!.4$	$0.15''$	1–5 μm	667,2000, 6000
NIFS GN	$3'' \times 3''$	$0.1''$	0.9–2.5 μm	~ 5000

2. GMOS

The Gemini Multi-Object Spectrograph (GMOS) instruments — one for each telescope — provide the primary optical imaging and spectroscopic capabilities at Gemini (Murowinski et al. 2002). Each instrument will have a lenslet/fiber-based IFU that sits in one of the three mask cassettes and it is deployed like any other GMOS slit mask. The IFUs are built by the University of Durham and the design of the first unit is described by Allington-Smith et al. (2002; also see Allington-Smith et al. in these proceedings). Commissioning for the first IFU was begun in September, 2001, and its performance has met or exceeded expectations. It was first offered to the community for use in the 2002A semester.

As the design of the IFU is covered elsewhere, this paper will focus on the data format and data reduction procedure. The IFU has two sub-fields — one with 1000 lenslets ($7'' \times 5''$), and one with 500 lenslets ($3''\!.5 \times 5''$) — separated by 1 arcminute so that one field can be used for sky subtraction. The light entering the lenslets is redirected by fibers into two pseudo-slits of 750 fibers each. These are imaged on the detector like regular longslits. The current detector is an array of three butted 2048×4608 pixel EEV CCDs with an effective size of 6144×4608. The gaps between the CCDs are equivalent to 37 pixels in width. The dispersion axis is along the long axis of the mosaic. When both IFU slits are used two banks of 750 spectra appear side-by-side on the detector and blocking filters must be used to avoid spectral overlap. However, either of the slits can be closed, resulting in one-half the field-of-view but allowing twice the spectral coverage. A raw GMOS file is a multi-extension FITS (MEF) file with one extension for each amplifier used for readout (usually 3 or 6).

All Gemini pipeline processing will be done within IRAF. The Gemini staff are writing packages of scripts for handling the data from facility instruments. Scripts for handling GMOS IFU data will be part of the GMOS package and will allow for the extraction, calibration, and analysis of the IFU spectra (Table 2). Most of these scripts are in draft form and the first release is planned for the middle of semester 2002A.

Table 2. IFU related scripts in the GMOS IRAF package

Task	Function
gfapsum	sum spectra in a spatial region
gfdisplay	display datacubes using ldisplay
gfextract	extract spectra, apply fiber throughput correction
gfmosaic	merge datacubes
gfquick	quick image reconstruction for target acquisition
gfreduce	apply reduction/calibration to object frames
gfresponse	determine relative fiber responses
gfskysub	subtract sky
gftransform	apply wavelength calibration
gscrrej	remove cosmic rays
gsreduce	bias subtraction
gswavelength	determine wavelength calibration

```
fxhead ifulampr400.fits
EXT#  EXTTYPE            EXTNAME       EXTVE DIMENS      BITPI INH OBJECT
0     ifulampr400.fits                                   16        artificial I
1      BINTABLE          MDF                 16x1500     8
2      IMAGE             SCI           1     1330x747    -32   F   artificial I
3      IMAGE             VAR           1     1330x747    -32   F   Variance: ar
4      IMAGE             DQ            1     1330x747    32    F   Data Quality
5      IMAGE             SCI           2     1330x749    -32   F   artificial I
6      IMAGE             VAR           2     1330x749    -32   F   Variance: ar
7      IMAGE             DQ            2     1330x749    32    F   Data Quality
```

Figure 2. The format of an example GMOS IFU extracted datacube. The Mask Definition File (MDF) is a binary table that contains information about each lenslet, such as relative position on the sky. There can be up to three extensions for each slit block extracted. Each image plane is an IRAF multispec file (one spectrum per line). The SCI extension has the extracted spectra. The optional VAR and DQ planes hold the variances of the spectra and the data quality flags.

The current extraction routine uses the IRAF task apall to find, trace, and extract the spectra. Most of the spectra are separated well enough that identifying the individual spectra is not a problem. However, the peaks of three low-throughput fibers cannot be distinguished from their neighbors, so they are lost. More sophisticated reduction techniques, such as deconvolution, may be able to recover these spectra. The current format of the extracted "datacube" is shown in Figure 2. The spectra are packed in 2D IRAF multispec images (one spectrum per image line) within a MEF file. The relative positions of the lenslets on the sky are contained in the binary table (MDF) extension. This format is similar in concept to the proposed Euro3D format. Tasks such as gfdisplay are used to visualize the 3D data. Additional analysis tools will be released as they are developed.

3. GNIRS

The Gemini Near-Infrared Spectrograph (GNIRS) is a fully cryogenic instrument sensitive from 1 to 5 microns. The instrument is being built by NOAO in Tucson and the IFU module is being built by the University of Durham. Similar to the GMOS IFU, the GNIRS IFU is in a cassette that is inserted into the beam on a slit slide. Since the instrument is cooled the IFU is an image slicer containing 21 diamond-turned mirrors that reformat the focal plane into a bank of spectra (Figure 3). The width of a slicer mirror is $0''.15$ and the slitlets are $4''.4$ long, giving 609 independent spatial elements. With slices of this width the IFU is optimized for tip/tilt correction rather than adaptive optics. Spectral resolutions for the short camera are $R = 667$, $R = 2000$, and $R = 6000$, depending on the grating. Delivery to Gemini South is expected to be toward the end of 2002.

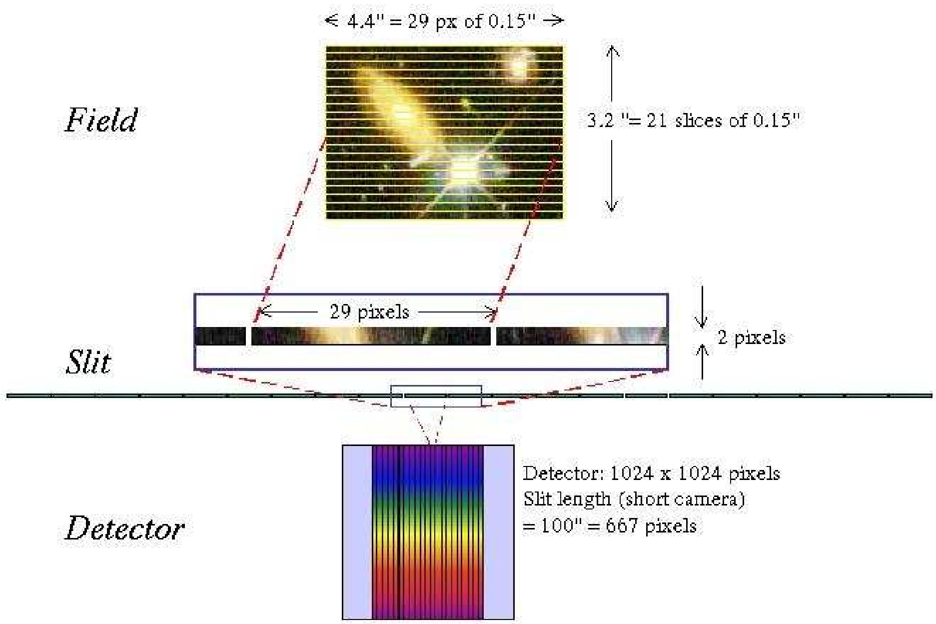

Figure 3. Schematic of the image-slicer concept used by GNIRS and NIFS (Allington-Smith, private communication). Specifications are for the GNIRS IFU. Cooled aluminum slicing mirrors divide the focal plane into a stack of slitlets. Reduction will be similar to infrared MOS slit spectroscopy except that full 2D spatial information is preserved.

4. NIFS

The Gemini Near-infrared Integral Field Spectrograph (NIFS), being built by the Australia National University, is designed to work behind the Altair adaptive optics system on Gemini North. To reduce cost and speed development the project is copying the the designs of the on-instrument wavefront sensor and the cryostat from the NIRI instrument already in use at Gemini North. The IFU is based on an image slicer similar to that used in GNIRS. The slicing mirrors have a projected width of $0\farcs1$ and the total field-of-view is $3'' \times 3''$. The 2048^2 Hawaii-II detector will give wavelength coverage from 0.9–2.5 μm with a spectral resolution of 5000. Delivery is expected in the middle of 2003.

5. Future

Future integral field spectrographs are likely to take advantage of the multi-conjugate adaptive optics system being developed for Gemini South. In this system multiple deformable mirrors will produce a uniform, near diffraction-limited PSF over a 2 arcminute field. Several designs for a spectrograph with multiple, deployable IFUs are under consideration.

6. Summary

Large collecting areas, good image quality (with or without adaptive optics), and infrared optimization make the Gemini telescopes well-suited for integral field spectroscopy. Therefore, Gemini will be offering both optical and near-IR IFU capability at both telescopes within the next two years. These instruments will be powerful tools for studies of galaxy dynamics, black holes, and ISM kinematics and abundances, to name a few possible projects.

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